Synoptic Data Collection with Multiple AUVs.

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1 LONG-TERM GOALS

The objective of this project is to develop and support the capability for synoptic and pseudo synoptic data collection through simultaneous operation of multiple AUVs. The goal is to use synoptic and pseudo synoptic measurements to efficiently characterize near land shallow water and sea bottom environments. An emphasis will be placed on shallow water hydrographic survey and locating and mapping mine like objects near, on, or partially buried in the bottom with multiple HF side-scan sonars systems. The characterization of the acoustical and optical transmission properties of the near bottom water column will be supported as well. Furthermore, the goal is to provide cost-effective means for simultaneous multiple vehicle operation with Zodiac based launch, chase, and recovery vehicles. This will have the added benefit of providing semi-clandestine vehicle deployment.

2 OBJECTIVES

Specifically with this proposal, we wish to address the navigation, logistical, control, and coordination, problems associated with synoptic and pseudo synoptic data collection with multiple AUVs. We wish to first characterize the relevant environmental structure associated with bottom and near bottom objects and then develop techniques for more efficient sampling. In addition this project will provide support to the University of South Florida Marine Science Department for the integration and deployment of several of their payloads and joint operations.

3 APPROACH

Three types of data collection missions uniquely benefit from simultaneous operation of multiple vehicles. These are: synoptic, pseudo synoptic, and cooperative adaptive sampling missions. The key problems in realizing the potential of AUVs for synoptic and pseudo-synoptic data collection are concentrated to a large extent in the navigation and synchronization techniques and the logistics of multiple vehicle operation. Moreover, cooperative adaptive sampling missions create additional challenges such as real time interpretation of sensor data, acoustic communications between vehicles, and cooperative adaptive control strategies. The technical focus of this project is on the development of the understanding and structure required to effectively carry-out multiple vehicle synoptic reconnaissance and detailed search and survey operations. We concentrate on developing, evaluating and demonstrating sensor systems and strategies for employing multiple UUVs to carry-out investigations of near shore, shallow water environments.

The modular nature of the Ocean Explorer AUV facilitates the parallel development and deploy-

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ment of multiple payloads. The basic Ocean Explorer comes equipped with a CTD and DVL which can provide profiles of bottom depth, current shear, and sound velocity. Payloads developed for this project include two high frequency (100 & 400 kHz) side scan sonars, 1 low frequency (65 kHz) chirp side scan and chirp subbottom profiler (2 - 10 kHz).

As part of this project two custom small ribbed boats are being built as support and chase vehicles. These chase boats will include a ramp to launch and recover Ocean Explorer AUVs. The chase boats will include the following equipment: compass, radio, DGPS, RF Modem, acoustic Modem, and an ORE LXT USBL tracking system. These chase boats will enable cost effective multiple vehicle operations. We will employ two different navigation schemes for the AUVs, namely, LBL and DVL aided DGPS..

4 WORK COMPLETED

Operation of the low frequency Chirp Side Scan Subbottom (CSSB) profiler payload as part of the acoustic measurement experiment conducted by USF of the Coast of St. Petersburg in the spring of 1997. In this mission a bottom mounted rotary side scan was used as ground truth for the AUV mounted CSSB. The AUV performed long range (4 - 6 hour) surveys of the area using DGPS navigation. Targets were placed in the array and detected by the AUV side scan. The side scan and subbottom data was delivered to USF for analysis.

Integration and operation of USF's PH sensor was completed in the spring of 1997.

Operation of the low frequency Chirp Side Scan Subbottom (CSSB) profiler payload as part of the acoustic measurement experiment in the Florida Keys in the spring of 1997 in support of USF and NRL. The AUV performed grid based surveys using LBL for navigation. The AUV side scan and subbottom data was delivered to USF and NRL for analysis.

Operation of the Ocean Voyager II with the Bottom Classification and Albedo Package in support of the CoBOP experiment during the summer of 1997. The AUV performed bottom optical surveys during the day and the Laser Line Scanner surveyed the same area during the night. The data was delivered to USF for analysis.

Performed surveys using the FAU turbulence payload in the Gulf Stream (3 knot current) down to over 115 m depth. Performed a variety of turbulence missions in shallower water including the outfall plume of the Boca Raton inlet.

Developed, integrated, tested, and successfully operated multiple AUVs using DGPS aided DVL based navigation. The first documented tests of navigation of simultaneous multiple AUVs using DGPS aided DVL navigation. The AUVs periodically surfaced to get differential GPS fixes. Two different GPS units were tested, the new pop up and an older fixed mast unit. The AUVs employed acoustic modems for reporting status and position updates to the surface support vessel. Integrated into the Ocean Explorer a new Coast Guard DGPS unit using a "Pop Up" retractable mast.

Joint operation of different AUVs (Ocean Explorer, REMUS and Odyssey) off from the same vessel were conducted as part of NAVO's AUV Fest. Data were collected and underwater navigation performance measured in a variety of sea states.

Construction, integration, test and deployment of two high frequency side scan payloads.

Multiple vehicle synoptic hydrographic survey using high frequency side scan payloads, DVL for altitude and current shear, CTD for temperature, depth, and sound velocity. This missions were conducted as part of NAVO's AUV Fest held near Gulfport Mississippi in September.

Enhancements were made to the AUV software to better support DGPS navigation, multiple AUV acoustic communication, acoustic modem updates of vehicle position and status, and control of side scan payloads.

Integration and Sea trials for USF's light sheet optical plankton counter payload were conducted in September. The first day of operations resulted in successful data collection and functional proof of the payload.

Integration and operation of WHOI/NUWC's acoustic communications payload was completed in August as FAU. Further sea trials and experiments were conducted in October at NUWC.

A payload has been constructed for WHOI's bathymetric sonar. Integration and Sea trials are planned for the middle of November. FAU's ambient acoustic imager payload is nearly completed. Integration and operation are planned before the end of the year. The UK SOC Autosub group will conduct joint AUV operations with FAU in Fort Lauderdale in December.

Procurement is nearly completed for the custom ribbed chase boats. Two boat hulls has been completed. An at sea test of one of the boats has been conducted. The command console and ramp are under construction. Multiple vehicle operations using the ribbed boats are planned for the end of the year.

The equipment for the video cameras for the side scan sonar payloads has been specified. Integration and operations are planned before the end of the year.

5 RESULTS

The efficacy of the Ocean Explorer's modular payload concept has been demonstrated. In 1997 we have integrated and operated 5 new payload sections (Ph, ACOMS, Light Sheet, 2 HF Side Scan) and 3 new sensor systems (Acoustic Modem, LBL, DGPS) with at least 2 more payloads planned before the end of the year. Some of these payloads were successfully integrated and operated at sea for the first time in the same day. This definitely proves the validity of the modular vehicle concept as an underwater sensor platform as an enabler of more rapid development of in situ sensor systems through the facilitation of parallel development of multiple sensor payloads and platform operational capabilities. The use of a component level distributed control systems coupled with a modular power system and standard mechanical and electrical interfaces has enabled rapid integration of new payloads.

The feasibility of using AUVs of the type and size developed at FAU for hydrographic survey has been demonstrated. Multiple grid based surveys of varying durations were conducted over a 1 week period in very shallow and shallow depths. We were successful in identifying underwater targets (simulated torpedo and scuttled ships) and were able to generate hydrographic map data. Much useful experience was gained in hydrographic survey operations and those areas where more work is needed have been identified, namely, increased reliability, streamlined launch and recovery, and better integration of data collection and analysis software. Synoptic data collection using two AUVs has been demonstrated for Hydrographic survey. Lessons learned include experience with tracking multiple vehicles, acoustic communications with multiple vehicles, and launch and recovery of multiple vehicles. More work needs to be done on data synchronization between vehicles.

Vehicle navigation performance using DVL based dead reckoning was quantified. Over a two kilometer distance included one turn the AUV measured its position to within 3 percent of distance traveled. The error is primarily due to inaccuracies in the magnetic flux gate compass. Peri-

odic DGPS fixes on the surface prevent the position error from growing. Hydrographic survey. Found ship found target. Good quality data. Further calibration of the compasses' deviation table could provide for accuracies near one percent of distance traveled.

Vehicle navigation using a commercially available LBL system was validated.

Over the course of the year we have gained valuable experience about vehicle reliability (100 at sea days of operations). As a result of this experience we are modifying the servo and thruster gear box and drop weight to increase reliability and reduce maintenance. This experience also contributed to many of the design decisions made with regards to the new mini-auv.

6 IMPACT/APPLICATIONS

As a result of the success of the Ocean Explorer modular concept the new mini-auv will be even more modular. As a result of the maintenance effort required to operate over 100 days at sea, a new gear box is being designed and the new mini-auv will employ plastic pressure vessels.

It is anticipated that DGPS aided navigation systems will be a standard feature of shallow water AUVs.

The number and types of sensor systems employed on AUVs has doubled or tripled in this year alone the impact on oceanographic measurements will soon begin to be felt once those sensor systems see enough at sea operations to collect significant data sets. The turbulence probe collectected for the first time turbulence and current shear data over the whole water column in the Gulf Stream.

The success of the AUV Fest has demonstrated that AUVs have the potential to complement and even replace current methods for Hydrographic survey. NAVO plans to continue the program under the anticipation that within the next few years AUV systems will be mature enough to initiate a procurement program.

Synoptic data collection using multiple AUVs is providing for new ways of collecting ocean data.

7 TRANSITIONS

The LBL system specified by FAU for AUV navigation is now a commercial product distributed by EdgeTech.

DGPS navigation on AUVs has been successfully demonstrated and is planned for implementation on other vehicles.

The Ocean Voyager AUV has been delivered to USF. The USF Marine Science Department and USF Center for Ocean Technology Systems now operate the Ocean Voyager with technical support provided by FAU. USF and WHOI now have Ocean Explorer Payloads.

As a result of the success of the hydrographic survey project NAVO is planning a continuing series of technical evaluations with the intent of eventually acquiring an AUV system for hydrographic survey.

8 RELATED PROJECTS

AUV Navigation and Self-Motion in Shallow Water, ONR.

Autonomous Oceanographic Sampling Network Development, ONR.

Enhancing AUV Operational Capabilities, ONR.

Synoptic Data Collection With Multiple AUVs, ONR.

ACOMS Acoustic Communication between UUV and Submarine, ONR ATD.

ONR MURI on Nonlinear Control

USF Projects, CoBop, UK Autosub, WHOI Remus, MIT Odyssey

Advanced Machinery Control Architecture (ACMA) Laboratory Development for Automated Navy Ship Auxiliary System Control, Reconfiguration and Failure Recovery, ONR.

Dependable Network Topologies with Network Fragment Healing for Component Level Intelligent Distributed Control Systems for Naval Shipboard Automation, ONR.

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